

# Development of an Automated Algorithm to Detect and Track Developing and Mesoscale Convective Systems

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## Abstract

An objective algorithm is developed which is capable of identifying convective cloud clusters (CCC) at the point of initiation, tracking any selected of all identified CCCs to maturity (MCS) and then to the point of dissipation and thereby accumulating some physical, morphological and radiative properties. The technique is able to account for periods of growth, propagating, merging, splitting and decaying, which take place during the lifetime of an individual cluster. The algorithm was tested using brightness temperature from merged infrared images of at least eight reporting geostationary satellites or channels at a spatial resolution of 4 Km and temporal resolutions of 30 minutes. The model data used is Weather Research and Forecasting (WRF) with the Advanced Research WRF (ARW) core simulated using the same spatial and temporal resolution with the satellite data for uniform comparison. This was the first attempt of developing such algorithm taking into consideration the uniqueness of West African convective systems. The algorithm loads an input (text) file where necessary inputs as preferred by the user, takes input file of satellite data or model's output in netcdf file format. The good graphical interface for interacting with user makes it very flexible and easy to use with little computer knowledge. Good results from the comparison and validation shows a good agreement between the model's output and satellite data shows the consistency in the tracking algorithm. The algorithm can hence be used for comparison or evaluating the performances of different Physics parameterizations/schemes in same model with the observed. It can also be used for comparison or evaluating performances of different models in simulating convective systems of the West Africa sub-region.

**Keywords:** convective systems, tracking, properties, propagation, growth and decaying.

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## 1.0 Introduction

West Africa sub-region experienced two major seasons as a result of the interplay between the maritime tropical and continental tropical air masses which have their source regions as Atlantic Ocean and Sahara deserts respectively. The prevailing of any of the airmasses gives the type of weather systems expected over the sub-region. The continental tropical airmass mostly referred to as northeasterly trade winds gives a dry, dusty and cold weather while the maritime tropical or the southeasterly becomes southwesterly on crossing the equator southwesterly to give the desired rainy season. However, the presence of southwesterly over the surface of West Africa sub-region does not guarantee abundance rainfall. Hamilton and Archbold (1945), classified the area around the line of discontinuity of these two air masses (Intertropical discontinuity - ITD) into four weather zones and later re-classified into five weather zones by Dhonneur (1971) by subdividing the active weather zone (C) in first classification of two (C1 and C2). Up to 150 km south of the surface position of the ITD (weather zone B), though overlaid by southwesterlies, experiences no significant weather while the next weather zone is the active zone (C or C1 and C2) produces heavy precipitation which accounts for over 70% and 90% of rainfall amount over Rainforest/Guinea and Sahel climatic zones respectively (Omotosho, 1985; Laurent *et al.*, 1998; Adefisan and Abatan, 2015 and Adefisan and Okewu, 2018). This active weather zone is characterised by strong convection hence convective systems that produce the heavy rainfall over West Africa sub-region.

West Africa is a vast zone where several types of mesoscale convective systems (MCSs) develop depending on the latitude, surface conditions and terrain conditions. A broad definition of a squall line (convective cloud cluster) that includes most, if not all, of its forms is a cumulonimbus cloud system which produces a contiguous precipitation area ~100 km or more in at least one direction. Different names and definition have been used to describe tropical mesoscale systems depending on shapes, sizes and some other morphological properties when observed. A compilation of these names and definitions was presented by (Rowell and Milford 1993). Throughout this study, mesoscale convective systems (MCSs) and developing convective systems (DCSs) will be used for the mature and growing/decaying small convective cloud clusters not yet matured respectively.

There are two major problems associated with the study of MCSs over West Africa. Firstly, there are sparse observational data network of synoptic and upper air stations and secondly, the physical and dynamical (including thermodynamical) processes that lead to their generation/initiation are not yet fully understood. The understanding of these systems has been gained through special experiments (e.g., pre-GATE SECNA in 1973, GATE in 1974 and COP in 1981) and through the use of satellite data and numerical simulation of the systems. In order to accurately identify the initiation, developmental and propagation processes in both satellite and modelled datasets, objective extraction of these morphological properties becomes a vital tool. This is achieved by developing an objective tracking algorithm that is capable of identifying a convective cloud cluster and monitors it until it grows to maturity (MCS) and continue to monitor it until it finally decays.

A few algorithms have been developed to track storms sizes and shapes and even MCSs over some other tropical regions. Tracking of MCS and its characteristics includes an objective and automated methods. For example, Velasco and Fritsch, (1987) over midlatitude South America; Williams and Houze, (1987) over South China; and Machado *et al.*, (1998) over the entire America. To the best of author's knowledge, the attempt over West Africa was made for the first time. Adefisan (2014) made the first attempt and also used in Adefisan and Okewu, (2018). Full description of the algorithm is in Adefisan (2014). it was slightly improved for use in Adefisan and Okewu (2018).

Detecting and tracking of convective systems using satellite imageries requires some processes. The first process is to take a threshold value of the brightness temperature (BT) of cloud tops. Different BT values from 245 K to 233 K have been used over different parts of the tropics with different reasons and at times for different types of MCS (Squall Lines (SL), Organized Convective Systems (OCS) and Mesoscale Convective Complexes, (MCC)) in all of the studies cited previously. In order to conform to the African Monsoon Multidisciplinary Analysis (AMMA) and with a little modification, a diameter of 200 km or more is used for MCS. Since the present study involves tracking of convective cloud system whose thermodynamics and structural properties before they develop into full blown MCS and through propagation till they decay will be investigated, two threshold diameters of 140 and 200 km are used for any Convective Cloud Cluster (CCC) and for MCS respectively as presented by Pearson *et al.*, (2010). In a similar fashion, outgoing longwave radiation between 240 to 210  $Wm^{-1}$  is also used for model output. The combination of temperature and diameter (radius) criteria is hereinafter referred to as T-R criteria. Thus, the life cycle of a given (CCC). The combination of temperature and diameter (radius) criteria is first met and the life cycle of such system ends when the criteria are no longer met, so that a CCC amplifying to an MCS signifies development while an MCS that becomes a CCC is decaying. A fully automated detecting and tracking algorithm for West Africa CS developed by Adefisan (2014) is this study. The Algorithm is referred to as DETecting and TRacking of West African Convective Systems (DETRAWACS).

## 2.0 Data, Materials and Methodology

The algorithm developed is capable of accessing both satellite imageries and model output in Netcdf (NETwork Common Data Form) format. The basic steps involved in this algorithm are as follows:

- (1) N timesteps of dataset (satellite or model output) of  $T_B$  (for satellite data and outgoing longwave radiation, OLR for model output) with regular time interval  $\Delta t$  are considered. For the data at time  $t_i$ ,  $0 \leq i \leq N$ , regions of consecutive systems are identified according to the T-R criteria. Points not meeting these criteria are set to null value, so that there are  $m$  CS(s) identified;
- (2) at time  $t_i$ , the  $k$ th CS ( $1 \leq k \leq m$ ) is first isolated and compared with the next time slice at  $t_{i+1}$  that has an areal overlapping with  $k$ . That is, a CS in the next time slice whose centroid is close to (within the threshold displacement) of initial identified centroid. A speed of 45 km/hr has been observed as a value close to the upper limit of the displacement speed of the centre of mass of an MCS by Machado *et al.*, (1998);
- (3) for each time  $t_i$  and each CS, structural, morphological and radiative parameters are determined. These include the horizontal area  $A$ , perimeter  $P$ , mean and variance of  $T_B$ , minimum  $T_B$  and fractional area  $F_c [= 100(A_{TC}/A)]$ , where  $A_{TC}$  is the area within CS such that  $T_B \leq 210K$ . This area is associated with cloud tops that reach heights above 13km. The CS center of gravity ( $X_{CG}$ ,  $Y_{CG}$ ) are defined as the weighted average –

$$X_{CG} = \frac{\sum_{i=1}^{Np} X_i T_{Bi}}{\sum_{i=1}^{Np} T_{Bi}} \quad (1)$$

$$Y_{CG} = \frac{\sum_{i=1}^{Np} Y_i T_{Bi}}{\sum_{i=1}^{Np} T_{Bi}} \quad (2)$$

- where  $X_i, Y_i$  are the pixel coordinates in the east-west and north-south directions respectively while the summation was carried out over all  $N_p$  pixels within the given CS; and
- (4) the orientation of the CS cloud shield is computed by determining its eccentricity, since a CS is always assumed to have or close to an ellipse shape.

The procedures described are similar to those of Carvalho and Jones (2001) except that they used maximum spatial correlation ( $r \geq 0.30$ ) technique for tracking the propagation of CS which can give error if there are two very close and similar CSs in the next time slice. The procedures are also similar to those of Villa *et al.*, (2008) but theirs could not handle cases of merging or splitting CSs. The two schemes mentioned here were also developed over Southern America and are not publicly available for use, hence it is imperative to develop one for West Africa systems.

Figure 1 shows the schematic flowchart of DETRAWACS with input from either imagery of brightness temperature of satellite or outgoing longwave radiation from numerical model's output. The algorithm takes some basic values such as the distance between successive points along east-west and south-north direction or the spatial resolution in km. The Infra-Red brightness temperature (BT) data used in this work is the Climate Prediction Centre (CPC) merged dataset. This dataset has been prepared by merging pixel resolution IR brightness data from Geostationary channel 8 and 10 (GOES/8/10), METEOSAT channel 7 and 5, and GMS geostationary satellite at a spatial resolution of 4km and temporal resolutions of 30mins. The satellite was sourced from ([http://mirador.gsfc.nasa.gov/collections/MERG\\_001.shtml](http://mirador.gsfc.nasa.gov/collections/MERG_001.shtml)). The model's output used in conjunction with the satellite data is the simulation of the Weather Research and Forecasting (WRF) using the Advanced Research WRF (ARW) core over the same period and using the same horizontal resolution with the satellite imagery.

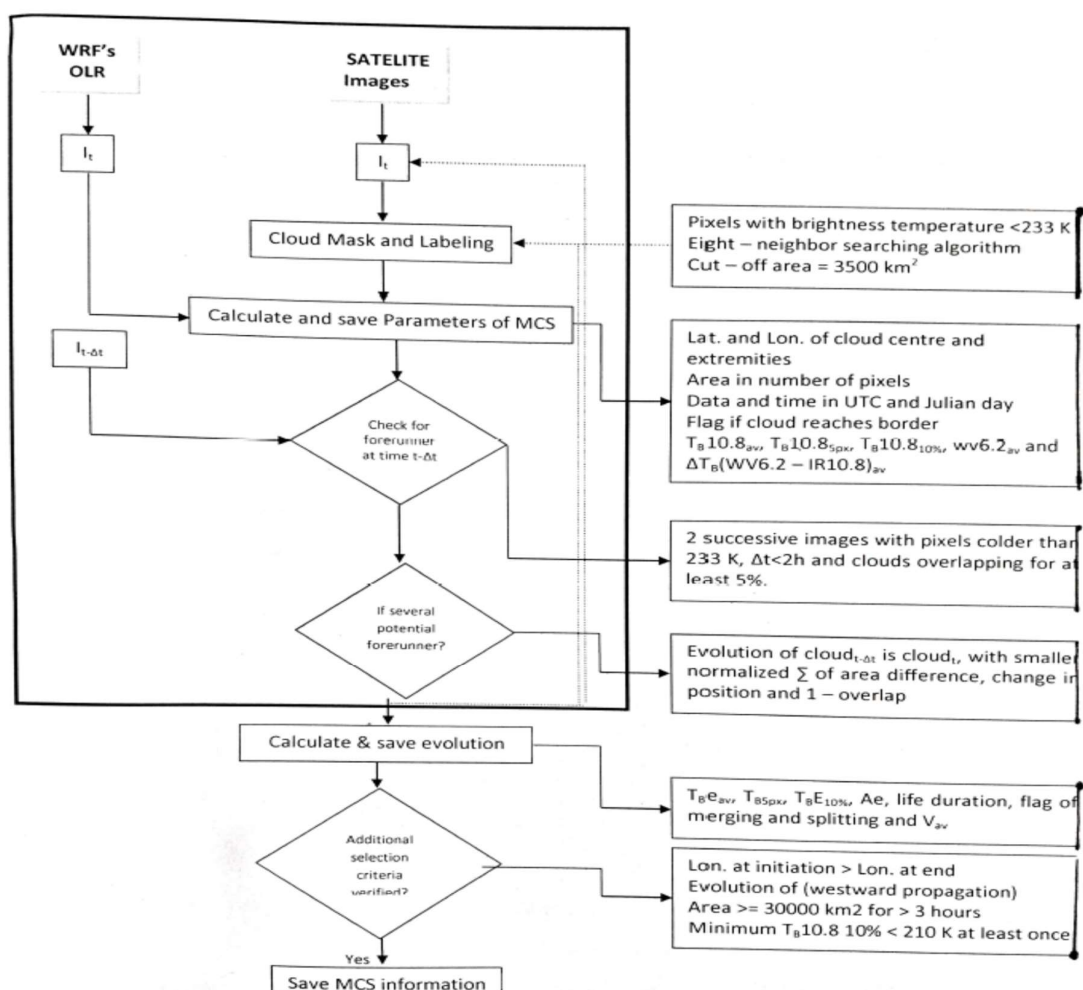


Figure 1: Schematic flowchart DETecting and TRacking of West African Convective Systems (DETRAWACS) showing some conditions and criteria used in the algorithm (Adefisan 2014).

### 3.0 Results and Discussion

The algorithm takes a text file as namelist input file where the users' preferred conditions and criteria are clearly spelled out in an organised manner. Options for units of some numerical inputs were given (e.g., option 1 for km or 2 for meters – for spatial resolution along east-west direction; option 1 for hour or 2 for minutes or 3 for seconds – for temporal resolution). The first graphical user interface displayed by the algorithm presents to the user the contents of this namelist file with some default values and a question is asked if the user wants to edit any of these values. If the user chooses to edit, then it allows edit to take place, save, check for any error and report before it finally goes to open the input netcdf file for the CCC tracking. The namelist input file also contains some inputs like the model/satellite data name and location. After all the items in the namelist input are correctly edited or otherwise, the dialog box asks if the tracking should commence. Response to this question signifies the direction of the procedure for tracking.

The algorithm presents a unix-based background to the user for all the interactions with the end user. Shown in Figure 2 is the screen displayed of DETRAWACS from the beginning to the end if the user chooses to commence tracking. For this study, the Ubuntu-based background graphical user interface is used.

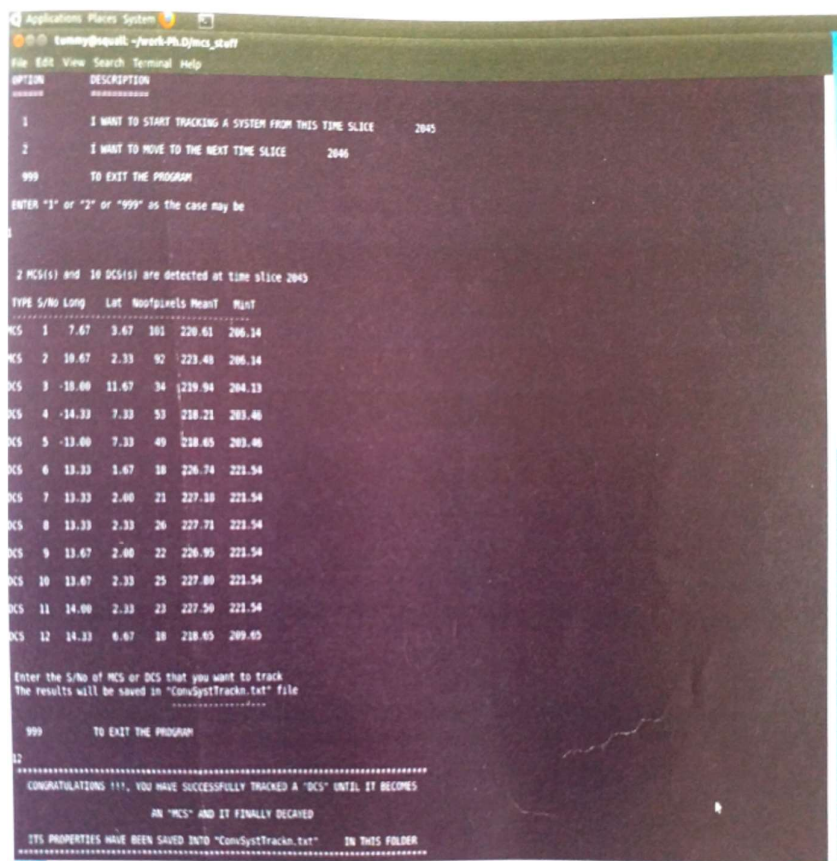


Figure 2: The interactive screen of DETRAWACS in running mode, displaying information and taking inputs from user.

At the commencement of running the tracking algorithm and after the user selects “commence running”, the starting time slice in the namelist will be displayed as follows:

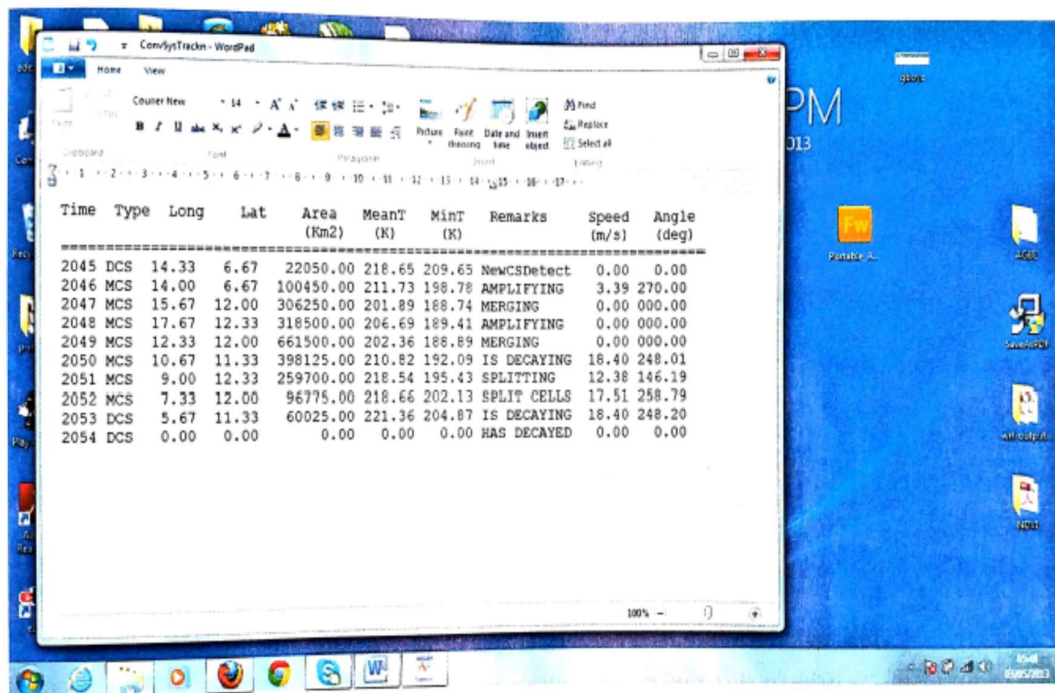
- (i) titled “OPTION” and “DESCRIPTION” are displayed with double underline;
- (ii) three options are displayed with appropriate description – option “1” with description “I WANT TO START TACKING A SYSTEM FROM THIS TIME SLICE” having a numerical time slice from the namelist input file written in front of the description. Option “2” with description “I WANT TO MOVE TO THE NEXT TIME SLICE” also with the numerical time slice plus 1 written in front of it. The third option is “999” having description “TO EXIT THE PROGRAM”;



- (iii) there is a command ‘ENTER “1” or “2” or “999” as the case may be’ and the command prompt waiting for user’s response; and
- (iv) any number entered apart from 1, 2 or 999 will result in displaying “error” dialog box and the same screen comes again. If this cycle is repeated three times, the program automatically ends.

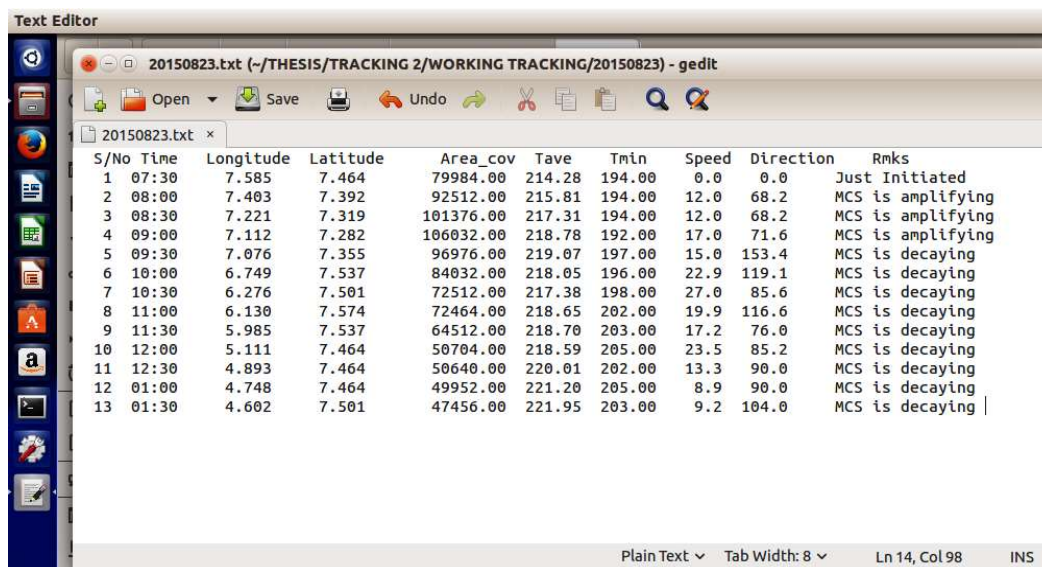
The last step was put in place to check error in entering a number other than the option given and for user who may be interested in moving round some time slices to see number of CCCs detected at each time slice. If option “1” or “2” is entered, then all the CCCs that meet the T-R criteria will be displayed. If at least, the widest diameter along one direction (major axis) of the CCC is between 140 and 199 km, the “TYPE” is marked as “DCS” (developing convective system while if it is 200 km or more, it is marked as “MCS”. Other properties of the CCC (MCS or DCS) like the centre of gravity (centroid – longitude and latitude), total no of contiguous pixel, average and minimum temperature (or radiation) are then accordingly displayed with the serial number. Then comes a command that “Enter the S/No of DCS or MCS that you want to track” and in the next line is a piece of information that “The results will be saved in ‘ConvSysTrackn.txt’ file” all followed by a command prompt waiting for the appropriate serial number of the CCC to track. An option of 999 is also given to exit the program. Any number greater than the total number CCCs identified (apart from 999) or less than 1 is treated as error and if the error dialog box appears three consecutive times, the program automatically stops and ends, else, the tracking is done and saved in the file indicated. If the correct number is entered, the CCC correspond to the number entered is tracked from the time slice up till the time the diameter is less than 140km where it is believed to have decayed beyond a CCC. All things being equal, the confirmation of successful tracking is finally displayed, the program stops and then prompt the user to press any for the screen to disappear.

The same folder that contains the namelist input file is also where the ‘ConvSysTrackn.txt’ file is archived. The content of the file is as shown in Figure 3, where the physical and radiative properties are displayed after opening the file. For each time slice of the tracked CCC, the following are gotten: the time slice from the satellite or model; type of the CCC; longitude (positive for <sup>0</sup>E) and latitude (positive for <sup>0</sup>N) of the centre; total area covered (km<sup>2</sup>); average temperature (K); minimum temperature (K); remarks, speed (ms<sup>-1</sup>) and propagation angle (degree). The remark is whether it is amplifying or decaying, merging or splitting etc. Figure 3 is after Adefisan (2014) while Figure 4 shows a similar output but with slight modification to the algorithm by converting the time slice to actual time of the day and saved the file name using date the CCC initiated as used in Adefisan and Okewu (2018). The file content in Figure 4 is more understandable for user generally than that of Figure 3. If more than one CCC initiated in a day is to be tracked, the user is expected to append the filename with -01, -02 (or -a, -b) at the end of the filename so as to distinguish different CCC tracked for a the same day, else the latest tracking will irrevocably erased the immediate old one.



Time	Type	Long	Lat	Area (Km2)	MeanT (K)	MINT (K)	Remarks	Speed (m/s)	Angle (deg)
2045	DCS	14.33	6.67	22050.00	218.65	209.65	NewCSDetect	0.00	0.00
2046	MCS	14.00	6.67	100450.00	211.73	198.78	AMPLIFYING	3.39	270.00
2047	MCS	15.67	12.00	306250.00	201.89	188.74	MERGING	0.00	000.00
2048	MCS	17.67	12.33	318500.00	206.69	189.41	AMPLIFYING	0.00	000.00
2049	MCS	12.33	12.00	661500.00	202.36	188.89	MERGING	0.00	000.00
2050	MCS	10.67	11.33	398125.00	210.82	192.09	IS DECAYING	18.40	248.01
2051	MCS	9.00	12.33	259700.00	218.54	195.43	SPLITTING	12.38	146.19
2052	MCS	7.33	12.00	96775.00	218.66	202.13	SPLIT CELLS	17.51	258.79
2053	DCS	5.67	11.33	60025.00	221.36	204.87	IS DECAYING	18.40	248.20
2054	DCS	0.00	0.00	0.00	0.00	0.00	HAS DECAYED	0.00	0.00

Figure 3: Content of ‘ConvSysTrackn.txt’ file as automatically generated by DETRAWACS.



S/No	Time	Longitude	Latitude	Area_cov	Tave	Tmin	Speed	Direction	Rmks
1	07:30	7.585	7.464	79984.00	214.28	194.00	0.0	0.0	Just Initiated
2	08:00	7.403	7.392	92512.00	215.81	194.00	12.0	68.2	MCS is amplifying
3	08:30	7.221	7.319	101376.00	217.31	194.00	12.0	68.2	MCS is amplifying
4	09:00	7.112	7.282	106032.00	218.78	192.00	17.0	71.6	MCS is amplifying
5	09:30	7.076	7.355	96976.00	219.07	197.00	15.0	153.4	MCS is decaying
6	10:00	6.749	7.537	84032.00	218.05	196.00	22.9	119.1	MCS is decaying
7	10:30	6.276	7.501	72512.00	217.38	198.00	27.0	85.6	MCS is decaying
8	11:00	6.130	7.574	72464.00	218.65	202.00	19.9	116.6	MCS is decaying
9	11:30	5.985	7.537	64512.00	218.70	203.00	17.2	76.0	MCS is decaying
10	12:00	5.111	7.464	50704.00	218.59	205.00	23.5	85.2	MCS is decaying
11	12:30	4.893	7.464	50640.00	220.01	202.00	13.3	90.0	MCS is decaying
12	01:00	4.748	7.464	49952.00	221.20	205.00	8.9	90.0	MCS is decaying
13	01:30	4.602	7.501	47456.00	221.95	203.00	9.2	104.0	MCS is decaying

Figure 4: The output file saved as the date of initiated CCC and time of the day used.

#### 4.1 Validation of DETRAWACS

The algorithm was further validated by comparing the results from model and satellite datasets in Adefisan (2014). The result, though, not here gave very good approximation of what was plotted on the spatial graphs. Figure 5 depicted the spatial distributions of BT and OLR for same time and resolution as described above. The tracked MCS is encircled in the plots and a rough estimate of some properties are in complete supports of the results of DETRAWACS. The corresponding value of OLR used is taken after Pearson *et al.*, (2010) which is from 240 – 210  $Wm^{-1}$ .

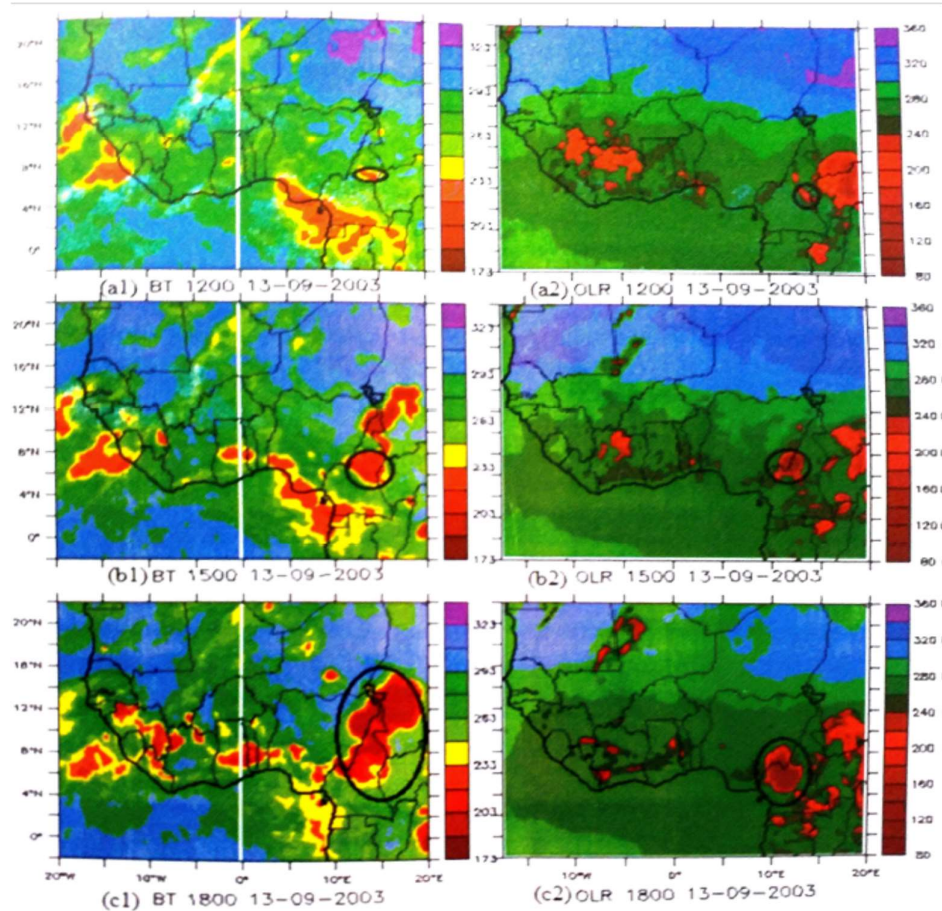


Figure 5: Comparison of spatial distributions of Satellite BT and WRF model OLR for the encircled and tracked MCS.

#### 4.0 Conclusion and Recommendations

An objective and automated algorithm capable of identifying and tracking a convective cloud cluster taking into consideration the uniqueness of West African systems is developed using linux-based FORTRAN language. The combination of thresholds for temperature (or radiation) and diameter used is called the T-R criteria. The criteria were set initially set to minimum values of a convective system should have and then track this until it becomes matured and at every time slice, remark is provided so as to determine if the systems is decaying or amplifying and/or splitting or merging or still moving as an entity. The program was tested with both satellite and model data and it was observed that there is a good agreement with what is plotted and value given by the algorithm. This was the first attempt of developing such algorithm taking into consideration the uniqueness of West African convective systems. The algorithm loads an input (text) file where necessary inputs as preferred by the user, takes input file of satellite data or model's output in netcdf file format. The good graphical interface for interacting with user makes it very flexible and easy to use with little computer knowledge. The algorithm can hence be used for comparison or evaluating the performances of different Physics parameterizations/schemes in same model with the observed. It can also be used for comparison or evaluating performances of different models in simulating convective systems of the West Africa sub-region. It is available for use if the author is contacted.

It is thereby highly recommended that the algorithm can be used for the purposes mentioned above or other similar purposes. It has flexibility of changing all the conditions and criteria needed to suit the user's propose study. Efforts are presently put in place to further improve the algorithm so as to access and read the model input file format in grib (and grib2). Another part being worked upon is to interface the program with Python scripts for better graphical user interface and hence present a robust user interactive forum where plots with several labelling is possible and even video of the tracked system may easily be produced.

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